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A STUDY OF THE PROPERTIES AND SINTERING BEHAVIOUR
OF CERTAIN NICKEL POWDERS

PROGRESS REPORT NO. 2

by

H.M. Skelly and C.F. Dixon

Nuclear and Powder Metallurgy Section

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ABSTRACT

The physical properties and sintering behaviour of blends of two nickel powders were investigated. One powder (termed S grade) consisted of spheroidal particles with a pebbly surface and a size range from + 100 mesh (about 1%) to -325 mesh (about 15%). The other powder (termed G-29 grade) consisted of dendritic particles, 98% of which were -325 mesh.

The apparent density, flow rate, green density and compression ratio of the blends were determined. The flow rate of S powder was improved by a 10% addition of G-29. Maximum apparent and green densities of blends of the two powders occurred at about 25% G-29.

Sintering behaviour was studied by heating non-compacted and compacted (60,000 psi) specimens at 1105°C (2025°F) for 2 hours. The density and porosity of the sintered blends were measured and their microstructures were examined. It was found that the porosity of non-compacted and compacted sintered blends decreased as the G-29 content increased.

Tensile tests carried out on the compacted and sintered blends showed an increase in strength with increasing G-29 content.

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1. INTRODUCTION

This report is the second in a continuing research into some of the fundamentals of powder metallurgy. An earlier report ⁽¹⁾ dealt with the relationship between particle morphology, physical properties, and sintering behaviour for eight samples of nickel powder. The present report describes the effect on properties and sintering behaviour resulting from blending two of these nickel powders.

2. TEST MATERIAL

The two nickel powders chosen for blending were S and G-29 grades*. The S grade powder is a standard product and consists of spheroidal particles with a pebbly surface, and the G-29 grade powder is a more specialized product consisting of agglomerates of dendritic particles. The S powder contains particles ranging in size from + 100 mesh (about 1%) down to -325 mesh (about 15%), whereas the G-29 is 98% of -325 mesh. Full details of the appearance, particle size, apparent density, flow rate and chemical analysis of the powders are given in the earlier report ⁽¹⁾.

3. EXPERIMENTAL PROCEDURE

The powders were blended in a twin-shell laboratory blender in the proportions of S + 10% G-29, S + 30% G-29, S + 50% G-29, S + 70% G-29 and S + 90% G-29.

Flow rate and apparent density of the blends were determined in accordance with Metal Powders Industries Federation (MPIF) Standards Nos. 3-45 and 4-45 (or 28-59), respectively. Green density was determined by calculation from the dimensions and weight of the compacts (MPIF Standard No. 13-62). Sintered density was determined by impregnating the compact with oil and weighing in air and water (MPIF Standard No. 8-50); this procedure also gave the interconnected porosity by determining the volume of oil absorbed. Total porosity was calculated from the density of nickel (taken as 8.90 g/cc) and the actual density of the compact.

* Sheritt Gordon Mines Limited Designations.

Specimens for sintering were prepared as described previously (1), some being compacted at 60,000 psi in a tensile specimen die and others being gravity-fed into graphite moulds. Sintering was carried out in hydrogen at 1105°C (2025°F) for 2 hours.

Tensile tests on the compacted and sintered specimens were carried out on an Instron machine.

Mounting, polishing and etching procedures used to prepare the specimens for microexamination were the same as described elsewhere (1).

4. RESULTS AND DISCUSSION

4.1 Properties of Blends Before Sintering

The S + 10% G-29 blend had a flow rate of 16.7 sec/50 g, but the flow rate of the other blends could not be determined as they clogged the flowmeter funnel. The flow rate for 100% S, reported previously, was 17.9 sec/50 g (1), indicating that the 10% addition of G-29 improved the flow rate slightly.

The apparent densities of the blends are listed in Table 1 and plotted in Figure 1. (All values for 100% S and 100% G-29 in Figure 1 and elsewhere are taken from the previous report (1)). Figure 1 shows that the apparent density is a maximum at about 25% G-29, indicating that optimum packing is obtained at this composition.

The green densities after compacting at 60,000 psi are listed in Table 1 and plotted in Figure 1. The latter shows that the plot for green density closely parallels that for apparent density.

The compression ratios of the blends during compaction at 60,000 psi were as follows:

% G-29	10	30	50	70	90
Compression ratio	1.4:1	1.46:1	1.61:1	1.71:1	1.94:1

The inverse relationship between compression ratio and apparent density is shown by Figure 2, in which these two properties are plotted against blend composition.

4.2 Properties of Non-compacted Sintered Blends

The sintered densities of the non-compacted blends are listed in Table 1 and plotted in Figure 1. It can be seen from Figure 1 that the density increases appreciably with increasing G-29 content up to about 30% G-29 and then increases at a slower rate. Comparison of this plot with that for apparent density (also in Figure 1) shows that the curves follow different courses, the sinterability of the G-29 powder apparently having a stronger influence than packing efficiency.

The total and interconnected porosity results given in Table 2 show that the porosity is mainly interconnected for all blends. There is also a general decrease in porosity as the G-29 content increases.

Figure 3 illustrates the microstructure of non-compacted, sintered 50% S + 50% G-29 and is typical for these blends. Because of the lack of interparticle contact there is little evidence of union between powder particles. The phenomenon noted in previous work ⁽¹⁾ of voids opening-up within the particles is clearly evident.

Microexamination of the sintered samples revealed that many of them were of non-uniform porosity, the centre area usually being less porous than the rest of the sample. This phenomenon was observed in G-29 and in blends containing G-29, and usually in compacted blends. However, it was also observed in non-compacted powders as illustrated in Figure 4, which is from earlier work in which G-29 was sintered for 4 hours at 1105°C (2025°F). The phenomenon is discussed below.

4.3 Properties of Compacted Sintered Blends

The sintered densities of the compacted blends are given in Table 1 and plotted in Figure 1. The plot in Figure 1 is similar in shape to that for the non-compacted sintered specimens.

The porosity results listed in Table 2 show that the porosity is mainly interconnected and that it decreases with increasing G-29 content - the trend is more marked here than it is for the non-compacted specimens.

Figure 5 illustrates the microstructure of the compacted and sintered blend of 50% S + 50% G-29 powders. It can be seen that there has been considerable bonding between the particles in contrast to the non-compacted blend illustrated in Figure 3.

Figure 6 illustrates the non-uniform porosity effect, referred to above, in a blend of 70% S + 30% G-29. This effect was most noticeable in blends of S + G-29 powders that had been compacted prior to sintering. As the G-29 content increased, the dense centre region tended to increase also.

Figure 7 illustrates a specimen consisting of 50% S + 50% G-29, and it can be seen that the dense area is considerably larger than in Figure 6.

The microspecimens used for Figure 4, 6 and 7 were polished in a manner that accentuated the variation in porosity, thus making it more readily seen in a photomicrograph. The central area in the specimens looks as though it were completely densified, but in fact it contains some porosity.

In a more comprehensive study of this effect, blends of S + G-29 were compacted and sintered at 1105°C (2025°F) for times of 1/2, 1, 1-1/2, 2, 3 and 4 hours, and then sectioned and examined. The effect was not observed in 100% S, 100% G-29 nor in the 90% G-29 blend. It was most noticeable in the 30% G-29 and 50% G-29 blends.

Non-uniform density, or porosity in sintered specimens is thought to be related to density variations within the green compact. It is known that density within a compact is not uniform throughout, even when the compact is prepared by pressing at both ends as in the present work ⁽²⁾. Bonding or adhesion between powder particles will occur more readily in regions where they are closely-packed. This density variation within a sintered compact has been observed previously in these laboratories in work done on sintered medallion blanks only 0.09 inch and 0.13 inch thick ⁽³⁾. The reason for the dense central region in the non-compacted specimens is less readily explained.

The results of tensile tests carried out on compacted and sintered S and G-29 powders and their blends are listed in Table 3. The ultimate tensile and tensile yield strengths are plotted in Figure 8. The results show that tensile strength increases with increasing G-29 content.

This work does not take into account the change occurring in size fraction range of the blends as the relative amounts of the two powders change. Thus, increasing the G-29 content not only introduces more particles with a morphology different from that of S powder but also increases the amount of -325 mesh fraction in the blend. The relative effects of particle size and morphology will be investigated in the next phase of the project.

5. CONCLUSIONS

1. The flow rate of S powder is improved by a 10% addition of G-29.

5. CONCLUSIONS (concluded)

2. Maximum apparent and green densities of blends of the G-29 and S powders occur at about 25% G-29.
3. The sintered density of uncompacted and compacted blends of G-29 and S increases significantly with increasing G-29 content up to 30% G-29 and then increases slightly from 30% to 100% G-29.
4. The porosity of non-compacted and compacted blends is mainly interconnected after sintering at 1105°C (2025°F) for 2 hours.
5. The porosity of non-compacted and compacted sintered blends decreases as the G-29 content increases.
6. Tensile strength of the compacted and sintered blends increases with increasing G-29 content.

6. ACKNOWLEDGEMENT

The laboratory work on which this report is based was performed by Mr. M. McGoey.

7. REFERENCES

1. H.M. Skelly and C.F. Dixon - "A Study of the Properties and Sintering Behaviour of Certain Nickel Powders. Progress Report No. 1". Physical Metallurgy Division Internal Report PM-R-68-9, Mines Branch, Department of Energy, Mines and Resources, Ottawa, (23 April, 1968).
2. W.D. Jones - "Fundamental Principles of Powder Metallurgy", Edward Arnold (Publishers) Limited, pp. 298-301 (1960).
3. J. McGoey and H.M. Skelly - "An Examination of Alloy Medallion Blanks Manufactured by Powder Metallurgy Techniques". Mines Branch Investigation Report IR 66-66, Department of Energy, Mines and Resources, Ottawa, (22 July, 1966).

HMS:CFD:lc

TABLE 1

Apparent, Green and Sintered Densities of Powder Blends

Powder Blend	Density (g/cc)			
	Apparent	Green (60,000 psi)	Sintered 2 hr at 1105°C (2025°F)	
			Non-Compacted	Compacted at 60,000 psi
S + 10% G-29	4.49	6.58	5.11	6.67
S + 30% G-29	4.57	6.82	5.68	7.29
S + 50% G-29	4.21	6.58	5.40	7.53
S + 70% G-29	3.71	6.36	5.79	7.70
S + 90% G-29	3.21	6.10	5.83	7.93

TABLE 2

Porosity of Blends Sintered at 1105°C (2025°F) for
Two Hours

Powder Blend	% Total Porosity		% Interconnected Porosity	
	Non-Compacted	Compacted	Non-Compacted	Compacted
S + 10% G-29	42.6	25.1	37.6	23.8
S + 30% G-29	36.2	18.1	35.3	17.8
S + 50% G-29	39.3	15.4	38.1	15.4
S + 70% G-29	35.0	13.5	35.4	12.6
S + 90% G-29	34.5	10.9	36.0	7.4

TABLE 3

Tensile Properties of Nickel Powders Compacted at 60,000 psi
and Sintered at 1103°C (2025°F) for Two Hours

Powder	UTS (kpsi)	0.2% YS (kpsi)	% El on 1 in.
S	5.12	2.18	6.0
S + 10% G-29	8.49	3.36	6.0
S + 30% G-29	8.34	6.12	2.0
S + 50% G-29	28.0	8.90	12.0
S + 70% G-29	35.1	10.80	15.0
S + 90% G-29	41.6	11.60	21.0
G-29	42.5	13.17	20.0

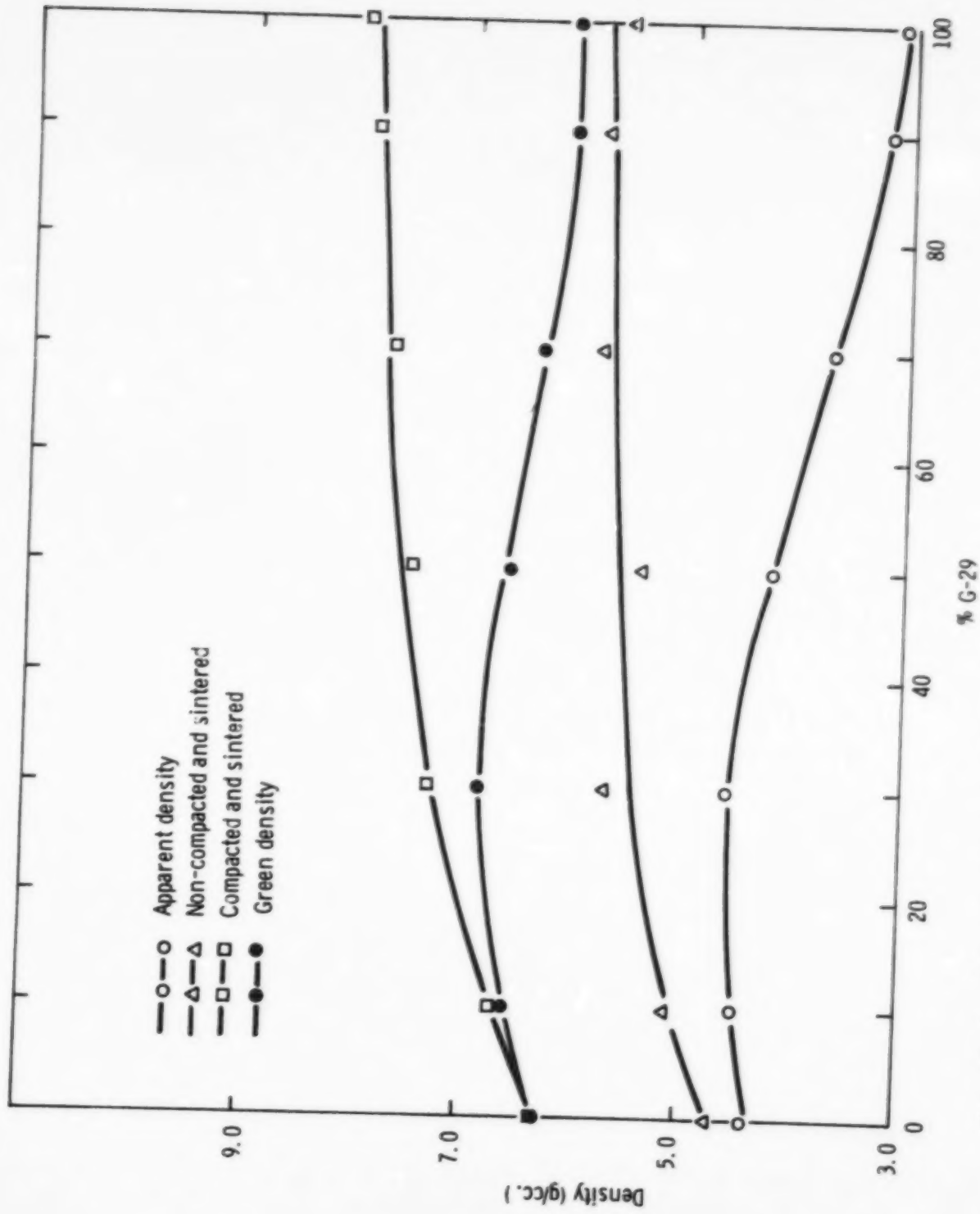


Figure 1: Density vs. blend composition for S and G-29 Nickel Powders

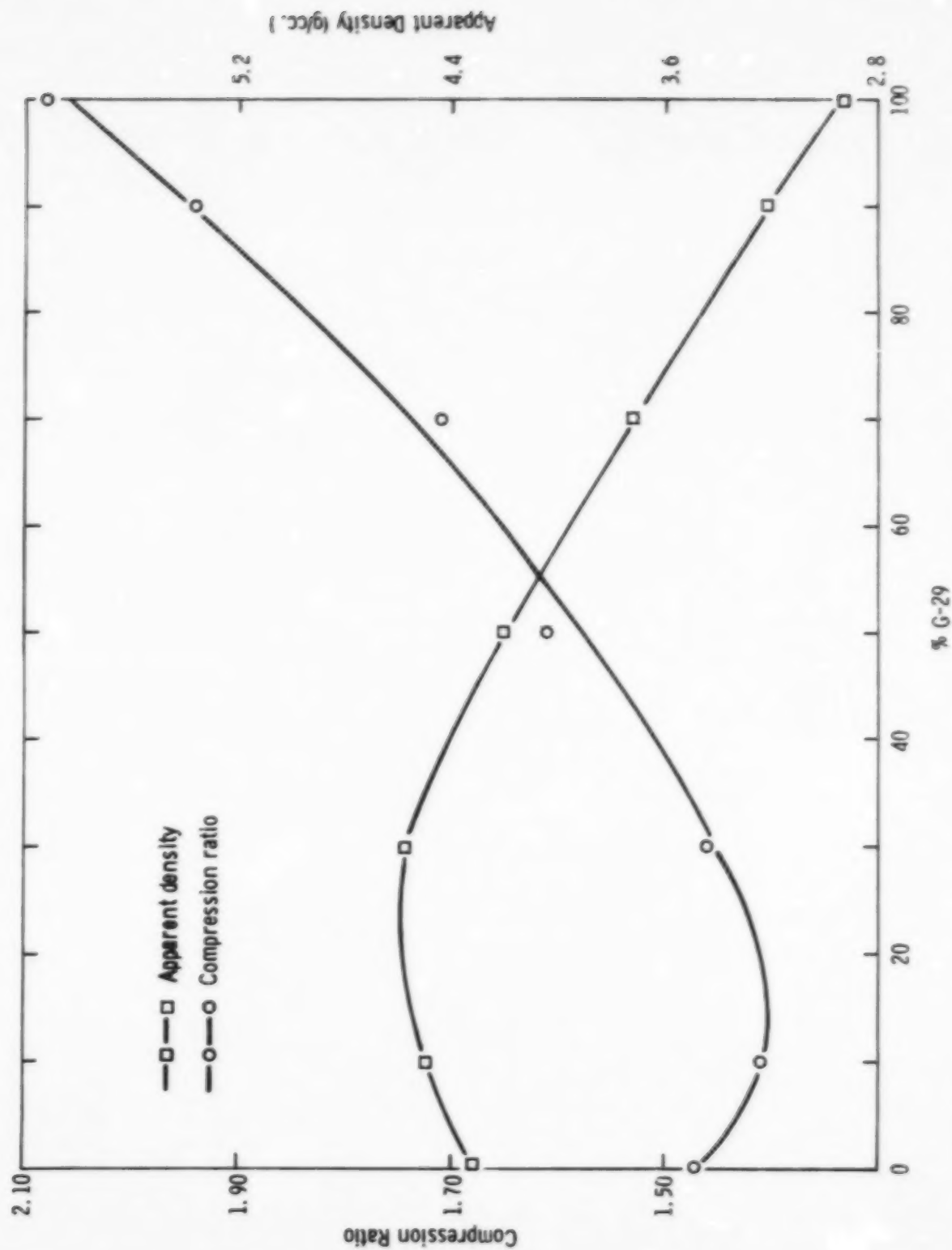


Figure 2: Apparent density and compression ratio vs. blend composition for S and G-29 Nickel Powders.

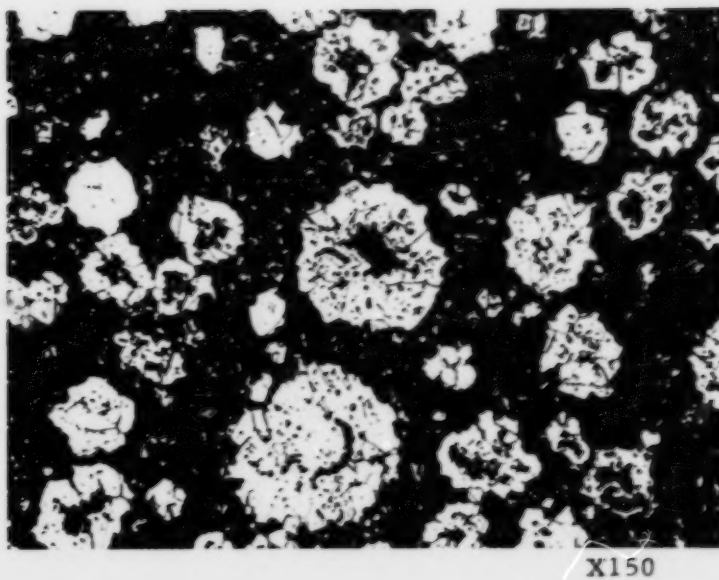


Figure 3. 50% S + 50% G-29. Non-compacted.
Sintered at 1105°C (2025°F) for 2 hours.
Etched.

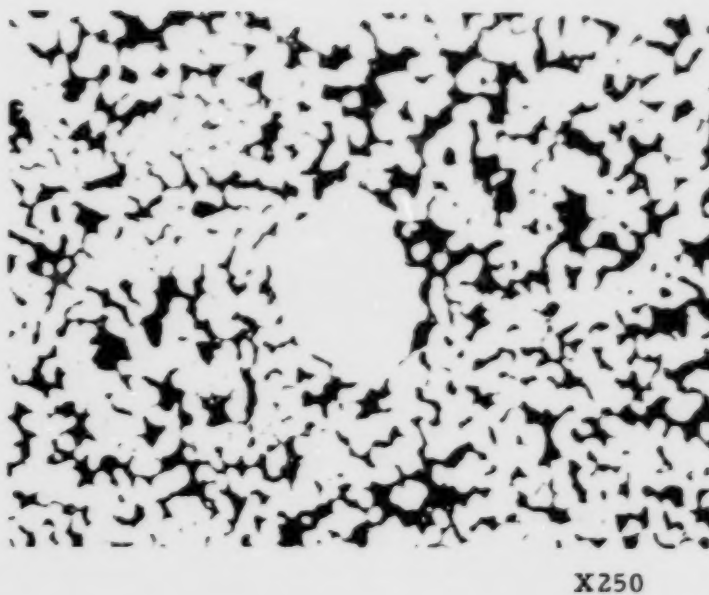


Figure 4. G-29. Non-compacted. Sintered at 1105°C
(2025°F) for 4 hours. As-polished.

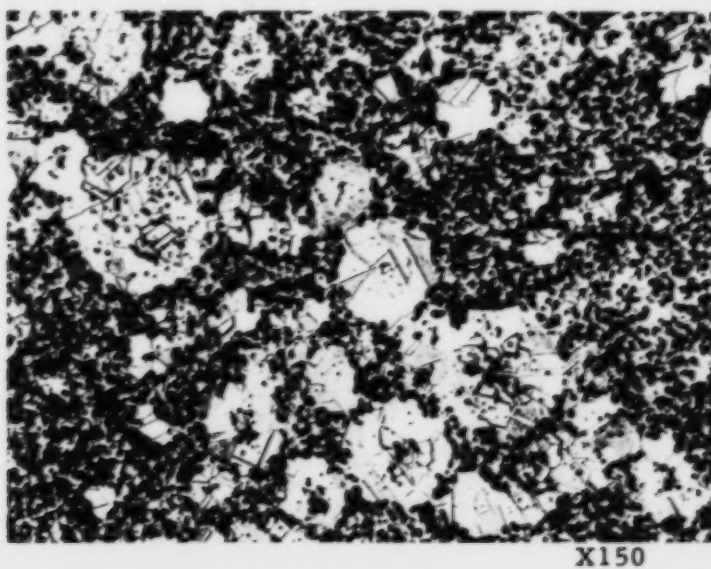


Figure 5. 50% S + 50% G-29. Compacted at 60,000 psi. Sintered at 1105°C (2025°F) for 2 hours.

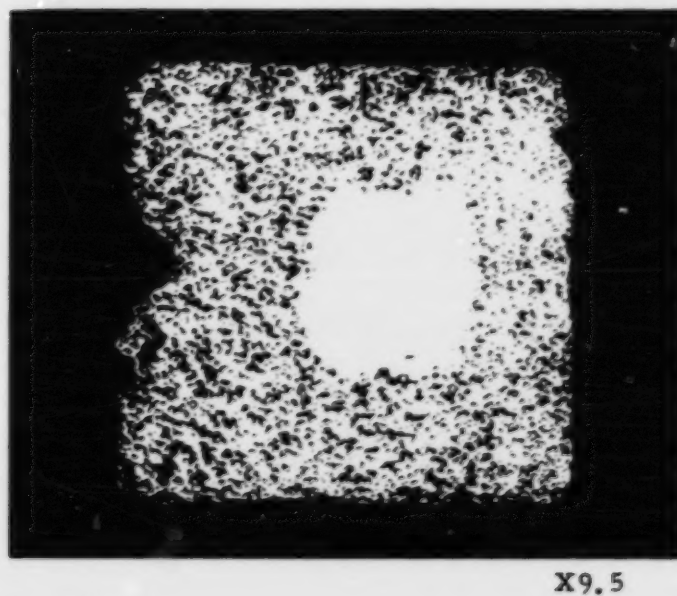
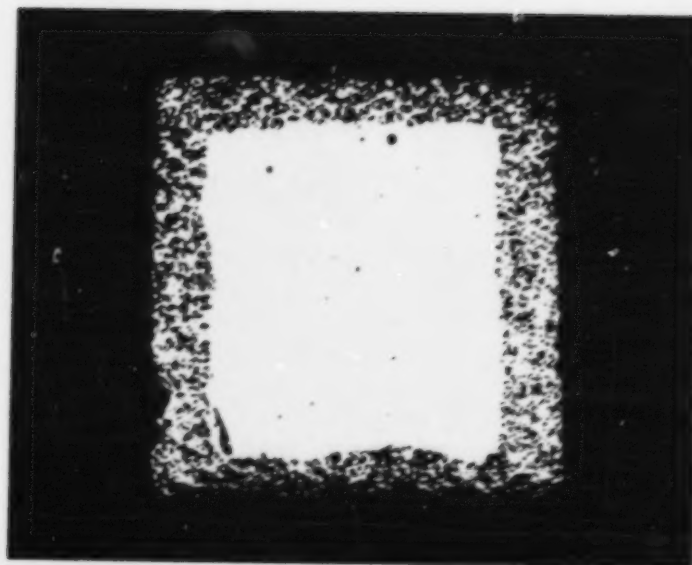


Figure 6. 70% S + 30% G-29. Compacted at 60,000 psi. Sintered at 1105°C (2025°F) for 2 hours. As-polished.



X9.5

Figure 7. 50% S + 50% G-29. Compacted at 60,000 psi. Sintered at 1105°C (2025°F) for 2 hours. As-polished.

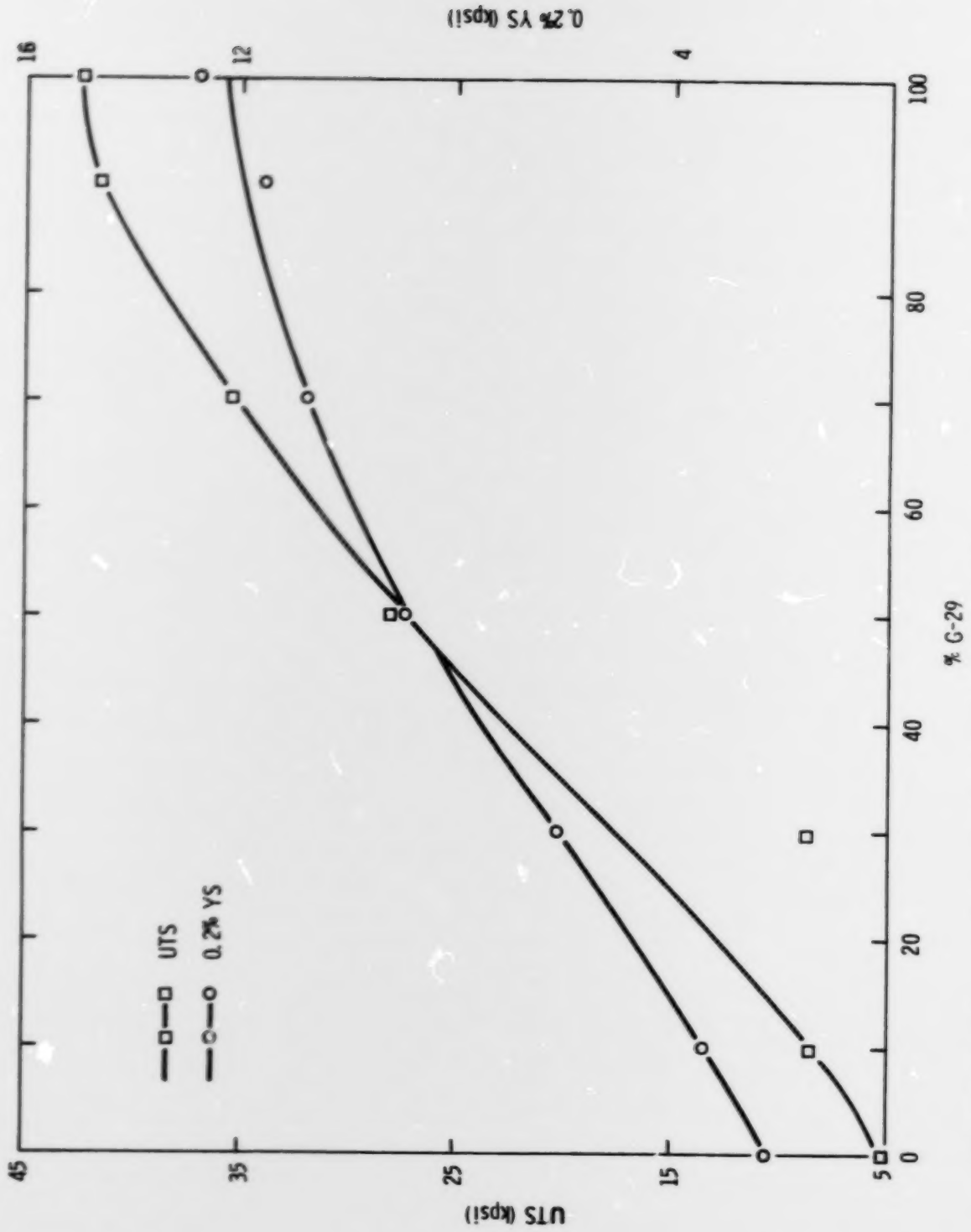


Figure 8: Tensile properties vs. blend composition for S and G-29 powders compacted at 60,000 psi and sintered at 1105°C (2025°F) for two hours